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Effects of Er:YAG Laser in Caries Treatment: A Clinical Pilot Study

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Background and Objective: **Various lasers have been suggested for cavity preparation. Pain reduction is expected as a potential benefit of laser usage. Among the systems studied in vitro, the Er:YAG laser offers a distinct combination of high ablation efficiency and low thermal side effects. Animal studies demonstrated that pulp damage can be avoided when appropriate laser parameters are used.**
Study Design/Material and Methods: **The present prospective clinical study was intended to test the practical applicability of the system and to investigate the patient's response. The study population consisted of 67 teeth on 33 subjects. Patient's reaction to pain was documented in four categories: no pain, little pain (like a brief pressure to the tooth), medium pain (like needle sticks), and strong pain (like a thermal shock test).**
Results: **For superficial cavities 200 pulses (SD: 114) were needed. At a pulse repetition rate of 2 Hz, the preparation time was 1.6 min (SD: 2.1 min). Deeper cavities required 391 pulses (SD: 251), or ~ 3.3 min (SD: 2.1 min). No loss in pulp vitality was observed. In 36% of the laser-treated teeth, no pain was felt, and in 57%, little pain was reported. With one exception, no local anesthesia was needed.**
Conclusion: **On the basis of this study, we suggest that the Er: YAG laser can provide caries removal and cavity preparation in an adequate preparation time with minimal patient discomfort. Laser Surg Med 20:32–38, 1997.**

Key words: laser; dentistry; clinical application; pain; caries therapy

INTRODUCTION

Dental treatment is recognized as a generally painful procedure. The introduction of local anesthesia has reduced the pain, but the fear remains, especially with respect to the injection. The noise and the vibrations of the mechanical drill during preparation also make the conventional preparation technique unpleasant for patients. Due to these undesirable sensations, it is not surprising that concentrated efforts have focused on new techniques such as lasers for painless caries removal.

During past decades, several in vitro studies with different laser devices were performed on dental hard tissue applications. Results were not encouraging [1–5]. Major problems have been thermal side effects, restricting the indications for lasers such as cw CO_2 and cw and pulsed Nd: YAG laser to the vitrification of the residual dentinal caries [4,6,7]. Considering the ablation rate, the short pulsed CO_2 laser seems to be suitable for hard tissue ablation. However, problems such as heat generation and plasma formation persist; see Miserendino and Pick [8] and Wigdor et al. [9] for an overview on these lasers for dental use.

Corresponding to the discouraging results of past in vitro studies, there have been few clinical investigations on the use of lasers for cavity preparation. In a retrospective clinical study, White [10] reported on restorations when a pulsed Nd:

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YAG laser was used for caries vitrification. Although he found the quality of restorations intact and all teeth remained vital, the sensitivity of the patients was not evaluated.

The Er:YAG laser at 2.94 μm [11,12] offers a new perspective for the effective removal of mineralized tooth tissues. Based on a thermally induced, mechanical ablation process, dental cavity preparations can be created by microexplosions without thermal damages to the adjacent hard and soft tissues [12–20]. Healthy enamel and dentin can be removed as well as carious tooth tissue. The laser-created defects contain rough walls without any signs of melting [18]. The ablation rate with ~ 80 mm^3/J in dentin is very high in comparison to the pulsed CO_2 laser at 9.6 μm with ~ 50 mm^3/J or the pulsed Nd:YAG laser with ~ 3–5 mm^3/J [21].

The Er:YAG laser can be applied to primary carious lesions and secondary carious lesions under old restorations. It is also possible to remove cements or composites with an ablation efficiency comparable to that of healthy enamel and dentin [22].

Animal experiments revealed that a thermal irritation of the pulp can be prevented if pulse repetition rates of 1–4 Hz with pulse energies of 100 mJ to 400 mJ with water spray are used [19,20,22–24]. Microcirculation studies of the pulp showed no inflammatory reaction with Er: YAG laser irradiation [25]. From the absence of the thermally induced inflammation, it can be hypothesized that there would be reduced pain associated with Er:YAG laser cavity preparation.

The purpose of the present study was, first, to test the applicability of an Er:YAG laser prototype under clinical conditions. Second, the patient's response to the laser preparation with respect to the different kinds of cavities and tooth locations was evaluated. Special interest was given to the pain perception. The investigation was planned as a pilot study to evaluate the practical aspects and the patient's acceptance. If the technical concept is adequate and the pain response of patients is positive, further clinical studies should be performed to compare the laser preparation with the mechanical preparation on a larger population with more examiners.

MATERIALS AND METHODS

A prospective clinical study was conducted in 1991 at the dental University of Ulm using a pulsed Er:YAG laser prototype (KaVo Biberach, System Aesculap Meditec, Tufflingen, Germany) for caries removal and for cavity preparation. The study population involved 67 teeth of 33 adult healthy patients with primary carious lesions. The clinical study was performed according to the guidelines of the declaration of human rights of Helsinki and with the approval of the ethical committee of the University of Ulm. Patients were informed before the laser treatment and had signed an informed consent document outlining possible risks and benefits.

For cavity preparation in enamel and dentin, a clinical prototype of the Er:YAG laser with a wavelength of 2.94 μm with an articulated arm and a 90° focusing handpiece in a noncontact mode was used. The spot size was ~ 0.7 mm and the pulse duration 250 μs. Pulse energy ranged between 250 mJ and 350 mJ for preparation of enamel and 150 mJ and 250 mJ for preparation of dentin. Pulses were applied with repetition rates of 2 Hz. The number of pulses was counted and the preparation time was calculated. During laser interaction, the treated surfaces were moistened by a continuous water spray.

The preparation was performed under visual control while testing the hardness of the remaining tissue by means of a dental probe. Enamel was conditioned using the Er:YAG laser in a defocused mode. After laser treatment, the teeth were restored with an underlying glassionomer cement and a composite filling without acid etching (Fig. 1). If a deep carious lesion was prepared, the dentin was covered with calcium hydroxide, and the tooth was restored as previously described. To determine pulpal health, thermal vitality tests and percussion tests were performed on the treated teeth before and immediately after laser irradiation. Bitewing or periapical radiographs were taken to evaluate presence of caries and apical pathosis before and 6 months after laser treatment.

Following laser preparation, patients were asked for their pain perception during laser treatment. Normally, an analogue scale for scoring of patient's pain perception is used. This is a suitable method for that kind of study, when the postoperatively increasing or decreasing pain or drug effects over a longer period are rated. However, in this study the patient had to rate just once the pain resulting from the short laser pulse impact to the tooth. Instead of the analogue scale a simple four categories scale was used for quantitative analysis. Patients had to select one of the follow-

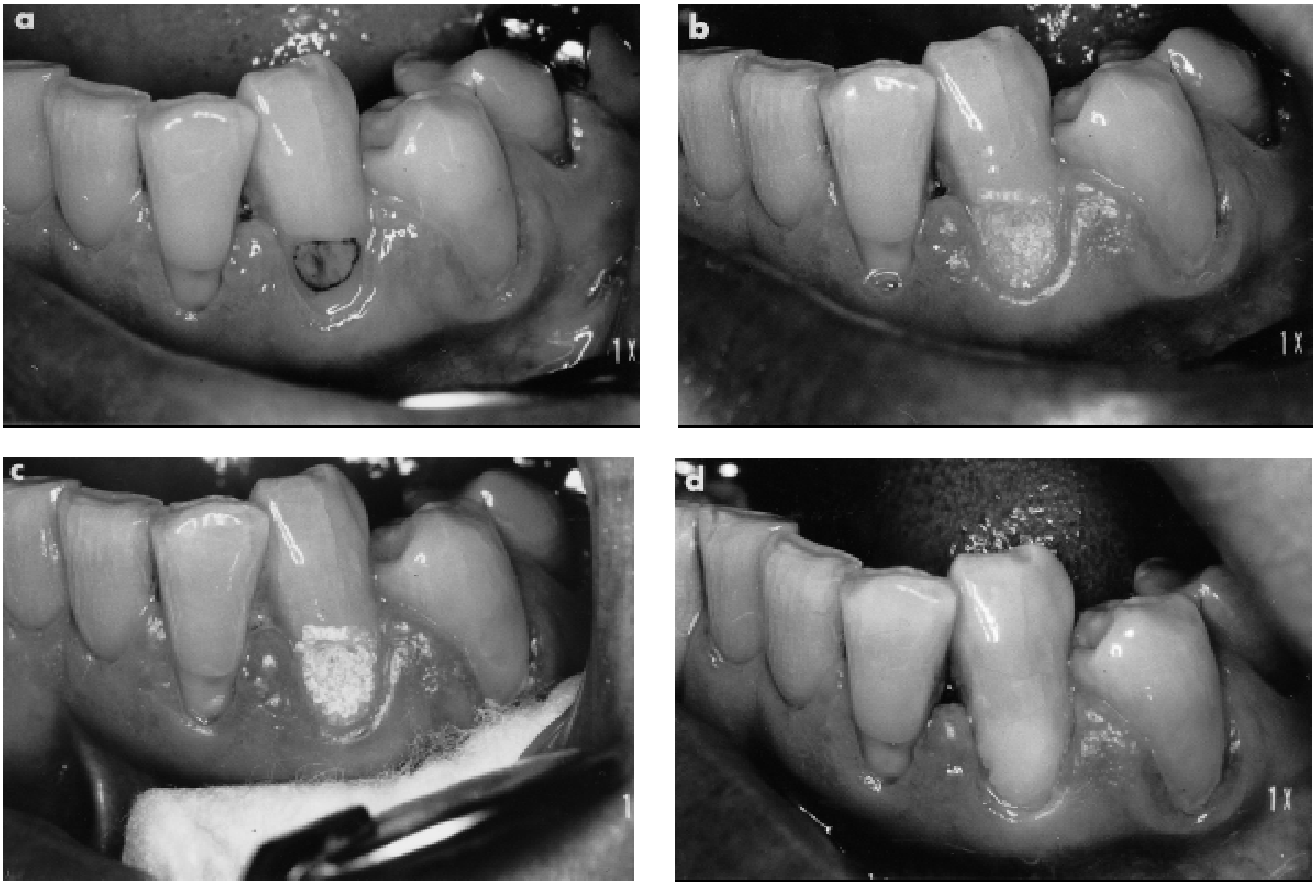

Fig. 1. Clinical laser treatment: **a:** Carious lesion in the cervical region of the lower left canine tooth. **b:** After laser preparation adjacent to the pulp. **c:** After laser etching of enamel and dentin. **d:** After restoration with calcium hydroxide and a composite the vitality test of the tooth is positive.

ing categories of pain reaction: 0 = no pain, 1 = little pain, 2 = medium pain, 3 = strong pain.

Afterward, the patients were asked to describe the quality of pain. In all cases laser preparation was started without local anesthesia. The patients were informed that they could have local anesthesia whenever they want.

An evaluation of following components was included: tooth location, age of subjects, pain perception with regard to age, sex, location, and number of prepared tooth surfaces, cavity depth, and laser energy used. Additionally, the applicability of the technical device such as handling, positioning of the laser unit, function of the water spray for cooling and of the pilot beam was considered.

RESULTS

The feasibility of the prototype of the Er: YAG laser in clinical use was positive. The articulated arm could be handled well for the most applications and carious lesions could be removed easily. However, on the distal parts of the molars, the removal of caries was restricted because of the dimension of the handpiece. Some problems existed to recognize the pilot beam, because the red light is scattered on the white tooth surface. With the fine water spray, enamel could be ablated well with pulse energies of 250–350 mJ. For small cavities < 1 mm into dentin, 200 pulses (SD: 114) on an average were necessary. Deep dentinal cavities with a remaining thickness of hard tissue to the pulp of 1 mm or less required an average of 390 pulses (SD: 250). An average preparation time of 3.25 min (SD: 2.1 min) was calculated for deep cavities, whereas an average time of 1.6 min (SD: 57 sec) was needed for small and superficial cavities. With respect to the number of prepared surfaces, an average preparation time of 1.9 min (SD: 1.6 min) for the preparation of one surface

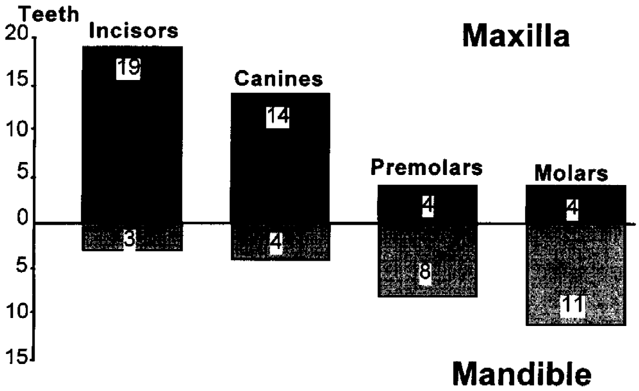

Fig. 2. Location of the laser treated teeth.

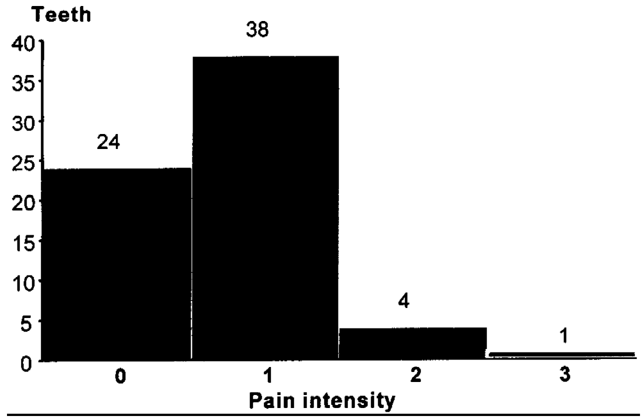

Fig. 3. Distribution of pain intensity: 0 = no pain; 1 = little pain; 2 = medium pain; 3 = strong pain.

and an average time of 2.9 min (SD: 1.8 min) for a restoration of two surfaces were evaluated.

The study population included 39 teeth of male subjects and 28 teeth of female probands. The age ranged from 18–65 years, with a mean of 36 years and a quite homogenous distribution. The 67 laser-treated teeth showed normal reaction to thermal vitality tests (ice) before and after laser preparation. All teeth were percussed after laser treatment and no pain was reported. On X-rays no apical pathosis was found after laser treatment, even 6 months postoperatively. The location of the treated teeth is shown in Figure 2. Among them, 37 teeth received restorations with one surface and 30 teeth with two surfaces. Deep carious dentinal lesions, 0.5–1 mm from the pulp, were removed in 41 teeth. In 26 of 67 teeth, cavities were prepared in dentin within a depth of 1–2 mm from the surface.

The results of the pain sensitivity due to the laser treatment showed in 24 of 67 teeth (36%) no pain, in 38 cases (57%) only little pain, and in 4 cases (6%) medium pain reactions (Fig. 3). Little pain was described as a brief pressure to the tooth, which could be tolerated easily. Medium pain was perceived as a brief needle stick, which could be tolerated without local anesthesia. Strong pain was reported as a thermal shock test. In this case local anesthesia was necessary during laser treatment. One patient, known for dental phobia, had a strong pain sensation after the first laser pulses and needed local anesthesia for further laser treatment. This pain was described as a thermal shock test, but not as long as a thermally excited pain reaction, e.g., after thermal vitality test.

Only little differences of pain intensity could be observed with respect to the age. Depending on the sex, it was noticed that little more pain was reported by males than by females (Fig. 4). Due to the tooth location, an average of 90% of the cavity preparations on all teeth were not or only little painful. With respect to the number of prepared tooth surfaces, the following results were obtained. If one tooth surface was prepared with the laser, 40.5% had reported no pain and 51.3% perceived only little pain. For two prepared surfaces of one cavity, the average percentage was 30% with no pain and 63.3% with little pain sensations (Fig. 5). Differentiating according to the location of the laser-treated surfaces, no correlation of the pain sensitivity with the prepared tooth surface was found. Minimal or no pain was perceived with a mean of ~ 90%.

As a result of pain perception depending on the depth of cavity, it can be noted that in 61.5% of the small cavities, no pain was reported and only little pain sensations in 34.5% (Fig. 6). For laser preparations adjacent to the pulp, 19.5% of the test persons showed no pain and 70.7% had little pain reactions. Due to the small number of cavities, no influence of the laser pulse energy on pain perception could be registered (Fig. 7).

DISCUSSION

Previous laser therapy for caries removal was mainly anecdotal. Those studies using lasers on hard tissues did not address patient comfort [10]. To our best knowledge, this is the first prospective clinical study using the Er:YAG laser for tooth preparation. Differing from other reports, the Er:YAG laser was not applied for carbonization of the residual caries as with the cw CO_2- or

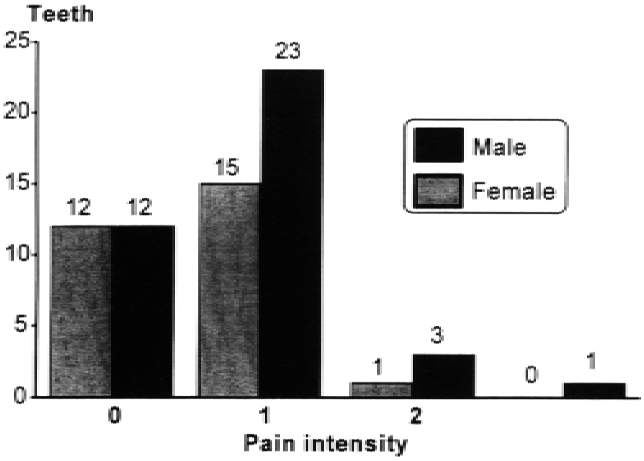

Fig. 4. Pain sensitivity depending on the number of treated teeth with regard to sex.

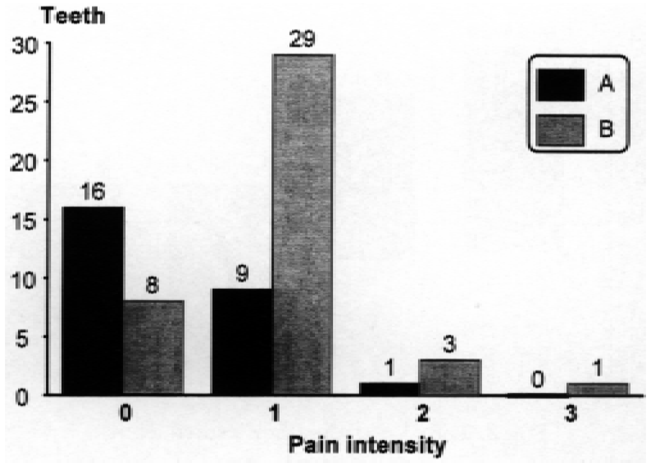

Fig. 6. Pain intensity depending on the distance of the prepared dentin to the pulp: **A** = small cavities within a depth of 1–2 mm, far from the pulp; **B** = adjacent to the pulp, with a remaining dentinal thickness of about 1 mm.

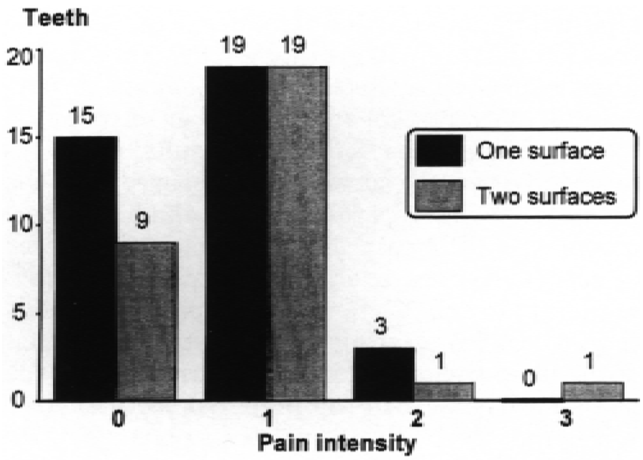

Fig. 5. Pain sensitivity depending on the number of surfaces of the laser treated teeth.

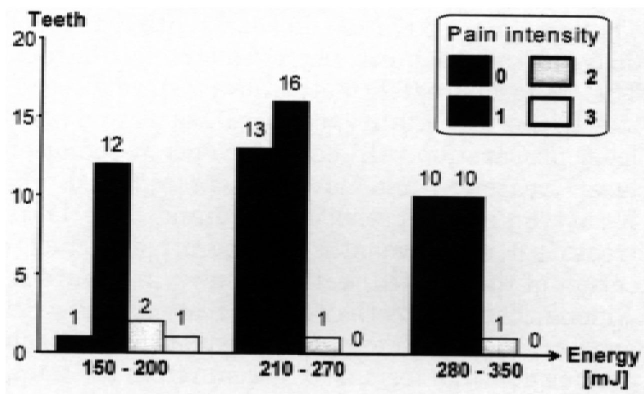

Fig. 7. Pain intensity with respect to the laser energy used for cavity preparation.

the pulsed Nd:YAG laser [7,10], but for preparation in enamel and dentin. The present study was conducted to test the clinical concept of the Er:YAG laser and the patient's reaction, because no experiences of patient's response to the laser preparation exist.

The results are encouraging for further clinical studies. Although the articulated arm can be handled well for the preparation of frontal teeth or premolars, the removal of distal carious lesions on molars is limited. That is the reason why mostly incisors, canines, and premolars were treated. The problems are the dimension of the handpiece and the restricted mobility of the articulated arm. The application could be improved by a fiber delivery system and a smaller handpiece, which have been developed as a result of this study. For better recognition of the pilot beam, a higher intensity was choosen. The additional water spray is useful for several purposes. The ablation side is cleaned and loosely adhering particles are removed by evaporating water. Another effect is that in keeping the ablation site wet, the ablation process is also maintained for consecutive pulses, particularly in enamel, and the fine water mist prevents the tooth from drying out and from heating. However, if a suction is clinically used, the water flow (mean 1.5 ml/min) should be adapted individually when treating a patient, since different suction techniques may draw off a part of the water spray before it reaches the tooth surface. If the water flow is not high enough, some burning smell can irritate the patient, which comes from the ablated hard tissue parti-

cles, but not from the treated tooth surface. The greater number of pulses resp. the longer preparation time for deeper cavities can be explained by the removal of a large amount of healthy tooth hard substances to create a cavity. From prior temperature measurements and animal experiments, pulse energies ranging between 150–350 mJ and pulse repetition rates of 1–3 Hz were found to be safe [14,19,25]. The risk of thermal damage to the tooth is very low, which was confirmed in this study by evaluating the tooth vitality.

Although the mechanical drilling may trigger pain sensations due to various causes, such as vibration, pressure, heat, and noise, the noncontact laser preparation seems to be comfortable to the patient. In 93% of the patients, no or only little pain was reported. The laser pulses were described by 57% of the patients as a brief pressure and by 6% as mechanical needle sticks simultaneously with the laser pulses. With the exception of one patient, no continuous pain was specified, which usually occurs after thermal excitation of the pulp, e.g., during mechanical preparation with insufficient water cooling. An explanation for the lack of pain could be that for the pulse energies used, which are much above the ablation threshold, most of the energy contributes to the ablation effect, whereas only a slight amount of the energy heats the superficial layer of the tooth. The following laser pulse removes the heated material. This heat cannot dissipate into the depth of the tooth. This could account for the observation of no thermal side effects such as neurogenic inflammatory pain. The lack of pain almost totally eliminated the need for local anesthesia. The clinical results were hypothesized as animal studies on microcirculation of the pulp, with Er:YAG laser showed no thermally induced pulp reactions [25].

Little differences in pain sensitivity were found concerning the sex of the patients. This might be explained by the greater pain tolerance of the female patients, which is generally accepted. Whereas the age of patients, location and number of prepared tooth surfaces, and the pulse energy showed no or only little influence to pain perception, the cavity depth seems to be the most important factor for pain sensitivity, similar to the mechanical treatment. However, no loss of vitality, no periapikal pathosis on X-rays, and no pain to percussion were registered, and only one patient needed local anesthesia during laser preparation. In all other cases the pain could be tolerated without local anesthesia and the quality of pain was different from a thermal shock test.

These first clinical dates indicate the Er:YAG laser as a suitable instrument for caries treatment. The scoring of patient's response to pain seems to be adequate for this kind of study, because it can be used without complex statistical evaluation as mentioned above. In a further study these positive effects of laser preparation were evaluated in comparison with the mechanical drill. This was performed in a multicenter study on five dental universities in Germany [26,27].

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